

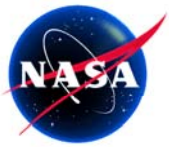
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# **Lidar Technology Development Strategy and Plans**

**Upendra N. Singh**

Electro-Optics and Controls Branch  
System Engineering Competency

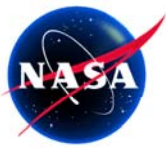
October 25, 2001



# Outline

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- **Background**
- **Lidar Systems Strategy**
- **Code R Augmentation**
- **Funding and Project Plan**
- **Conclusions**



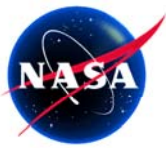
# Earth Science Independent Laser Assessment Report

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**Earth Science conducted an Independent Laser Assessment Review of its missions involving lasers and lidars. The panel members were from DoD, NOAA, National Reconnaissance Organization, Sandia National Laboratories, and University.**

## **Observations:**

- Laser technology for spaceflight is still in its infancy compared to many other technologies
- Testing requirements for spaceflight certification have not been established for the solid state lasers expected to fly over the next 10 years
- Requirements for cleanliness and contamination control for spaceflight certified lasers do not exist
- Lack of reliable diode laser suppliers is an area of serious concern, given the long-term need for future laser-based remote sensing instruments
  - Suppliers abandoning laser pump market for fiber-optics communications market
  - Sources issue shared by DoD and DOE
- In-depth laboratory testing of lasers and optics under space-like conditions must be performed

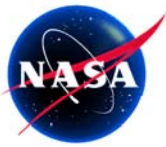


# Earth Science Independent Laser Assessment Report

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## Panel's Key Recommendations:

- NASA should examine its current mechanism to bring high risk components to TRL levels necessary for a high probability of success prior to the proposal process
- NASA should consider identification and intensive development of critical fundamental technology elements applicable to multiple missions
- NASA needs to develop guidelines that define how basic laser technology development is carried out among the Centers and private vendors
- NASA should create a "Super Laser Research Center" that is managed by NASA HQ and consists of the laser research teams of the Centers, in order to maintain its internal laser expertise
- A technology alliance should be formed among NASA, USAF, NOAA, NSF, and DOE for the development of space-based active sensors and related enabling technologies such as lasers
- NASA should consider forming a coalition between government agencies to assure a supply of diode pump lasers



# Integrated NASA Lidar Systems Strategy Team

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## GSFC/LaRC

- **Robert Afzal**, Technology Advisor, Laser Remote Sensing Branch
- **Norm Barnes**, Technology Advisor, Laser Systems Branch
- **Bruce Gentry**, Science Advisor, Mesoscale Atmospheric Branch
- **Bill Heaps**, Co-Lead, Head, Laser and Electro-optics Branch
- **Syed Ismail**, Science Advisor, Chemistry and Dynamics Branch
- **Upendra Singh**, Co-Lead, Head, Electro-Optics and Controls Branch

## ESTO:

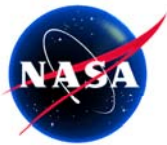
- **Frank Peri**, Instrument Program Manager

## LaRC/GSFC Co-ordinators:

- **Steve Sandford**, LaRC
- **Mary Kicza**, GSFC

## HQ Co-ordinator:

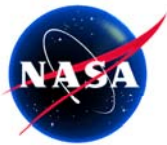
- **Tom Magner**, NASA, HQ



# Charter of INLSST

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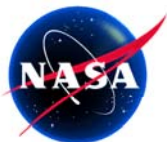
- Identify **NASA's requirements for lidar systems** in the coming decade, given Enterprise strategic plans, scientific requirements and proposed missions.
- Identify the **key technologies** required to achieve NASA's lidar systems requirements and establish, where possible, a realistic technology readiness level for those technologies. Indicate when classes of missions may be enabled, given the current TRL's of the key required technologies.
- Identify, at a top level, what the **respective roles** of industry, academia and government should be in the pursuit of these technologies.
- Identify parallel technology development needs in other government agencies (DoD, DOE, etc.) and recommend collaborative efforts to leverage those activities.
- Recommend an **investment strategy** to bring the technology readiness of the enabling lidar technologies to appropriate levels, which includes:
  - Level of investment
  - Time criticality of investment
  - Approach (competed vs. directed research)
  - Proposed performance metrics



# **INLSST Approach**

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- **Formulation of a joint LaRC- GSFC technologist team**
- **Identified critical and high risk technology elements**
- **Assessed state-of-the-art and needed technology level**
- **Strategy leading to technology maturation for space**
- **Paradigm Shift: Mature enabling technologies leading to space missions rather than developing technologies as part of mission**
- **Close collaboration, co-operation and effective communication between two lead lidar centers**
- **Involvement of other centers, government agencies, academia, and industry in leveraging and partnering for advancing critical technologies**



# **Integrated NASA Lidar Systems Strategy Team Report**

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**Presentation to**

**Daniel S. Goldin**, NASA Administrator

**By**

**Ghassem R. Asrar**

Associate Administrator  
Earth Science Enterprise

**Samuel L. Venneri**

Associate Administrator  
Aerospace Technology Enterprise

**Jeremiah F. Creedon**

Director, NASA LaRC

**Alphonso V. Diaz**

Director, NASA GSFC

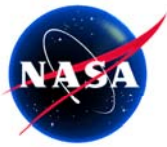
**William S. Heaps and Upendra N. Singh**

Co-Leaders

Integrated NASA Lidar Systems Strategy Team (INLSST)

**June 18, 2001**

**Draft Copy**



# Overview

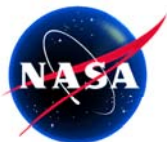
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Laser based instruments are applicable to a wide range of Earth Science, Aerospace Technology, Space Science, and Human Exploration and Development of Space Enterprise needs

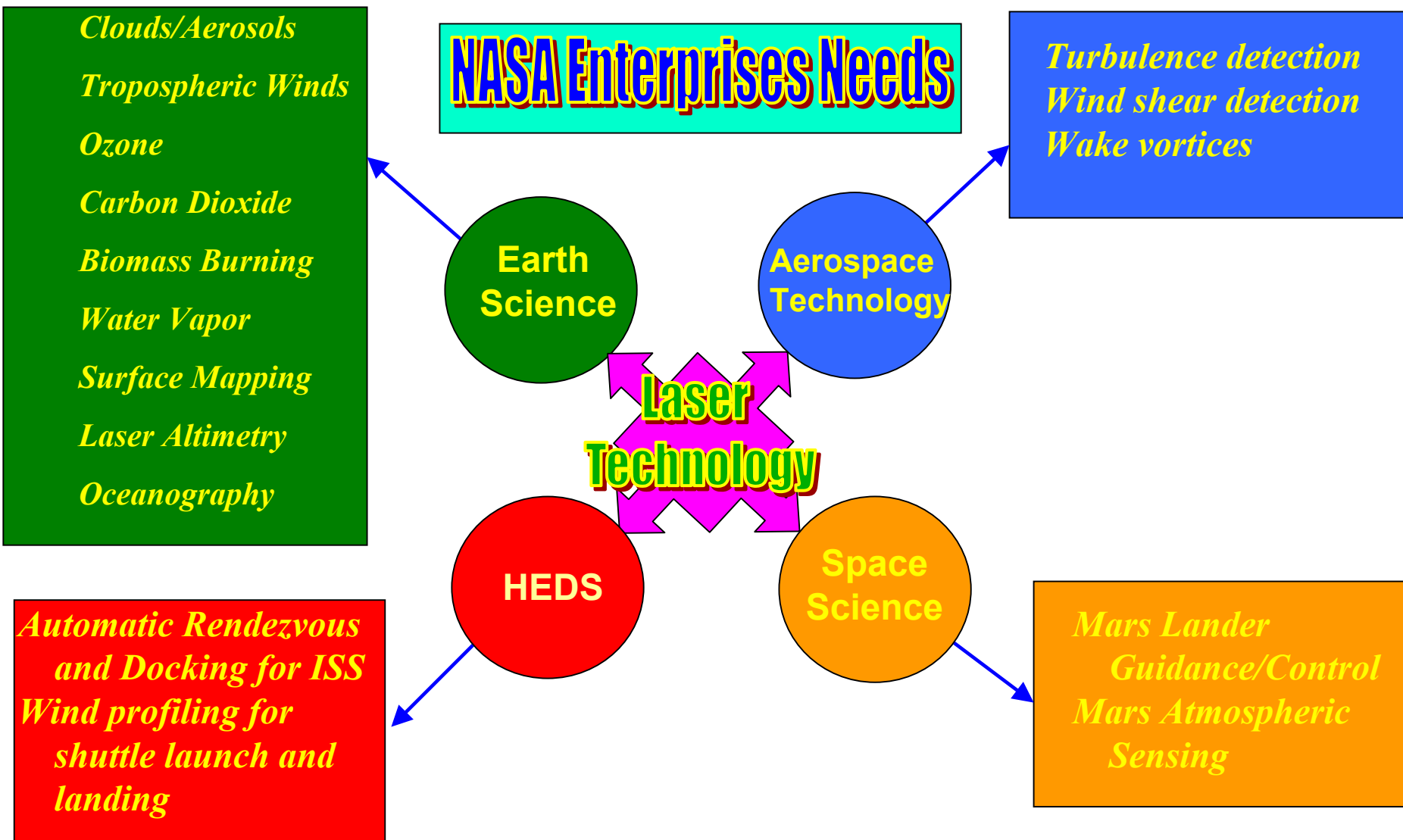
Risk in lidar missions can be significantly reduced by progress in a few key technologies

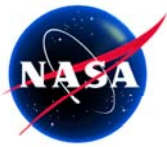
Modest NASA investment towards proposed strategy will have significant impact on future space-based active remote sensing missions

Strategic alliance with other government organizations, industry, and academia for leveraging and accelerating advancement of key technologies



# Lidar is a Multi-Enterprise Need



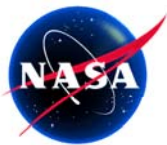


# Advanced Active Instrument Technology

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## Key Priority Measurements for Earth Science Enterprise

- Cloud/Aerosols and Radiative Forcing
- Tropospheric Winds
- Tropospheric Ozone
- Carbon Cycle (CO<sub>2</sub>, Biomass)
- Surface Mapping
- Oceanography

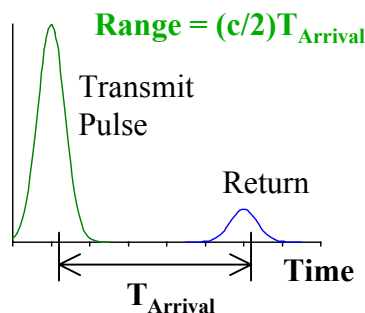
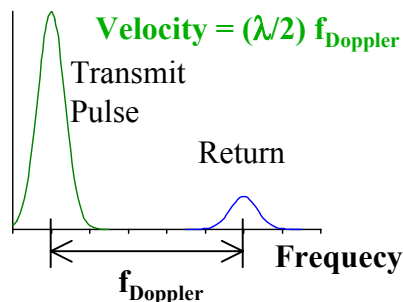


# Advanced Active Instrument Technology

## Lidar Techniques

### Doppler Lidar

- Wind Fields
- River Flow

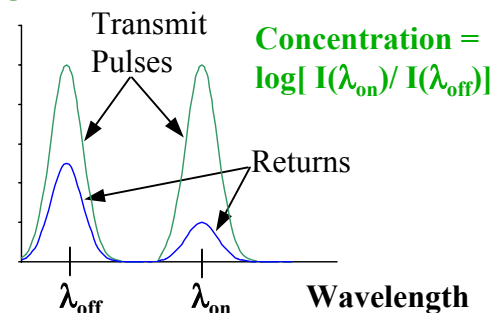


### Altimeter Lidar

- Ice Sheet Mass and Topography
- Vegetation Canopy
- Land Topography
- Oceanography

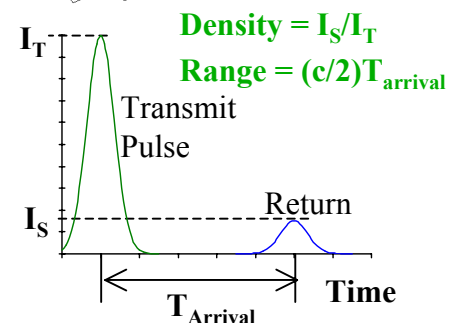
### Differential Absorption Lidar (DIAL)

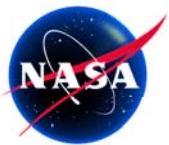
- Carbon Dioxide
- Ozone



### Backscatter Lidar

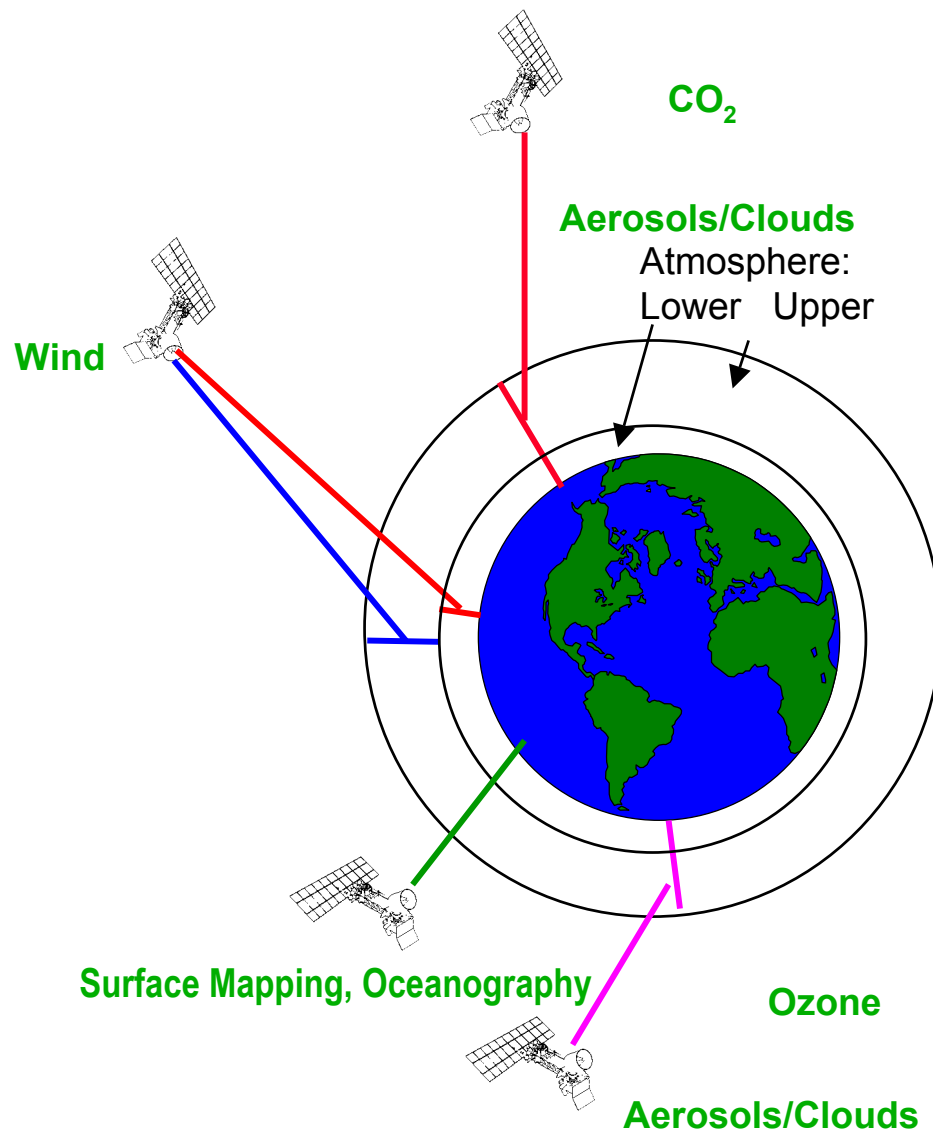
- Cloud
- Aerosol

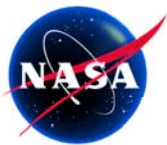




# Earth Sciences Application Focus

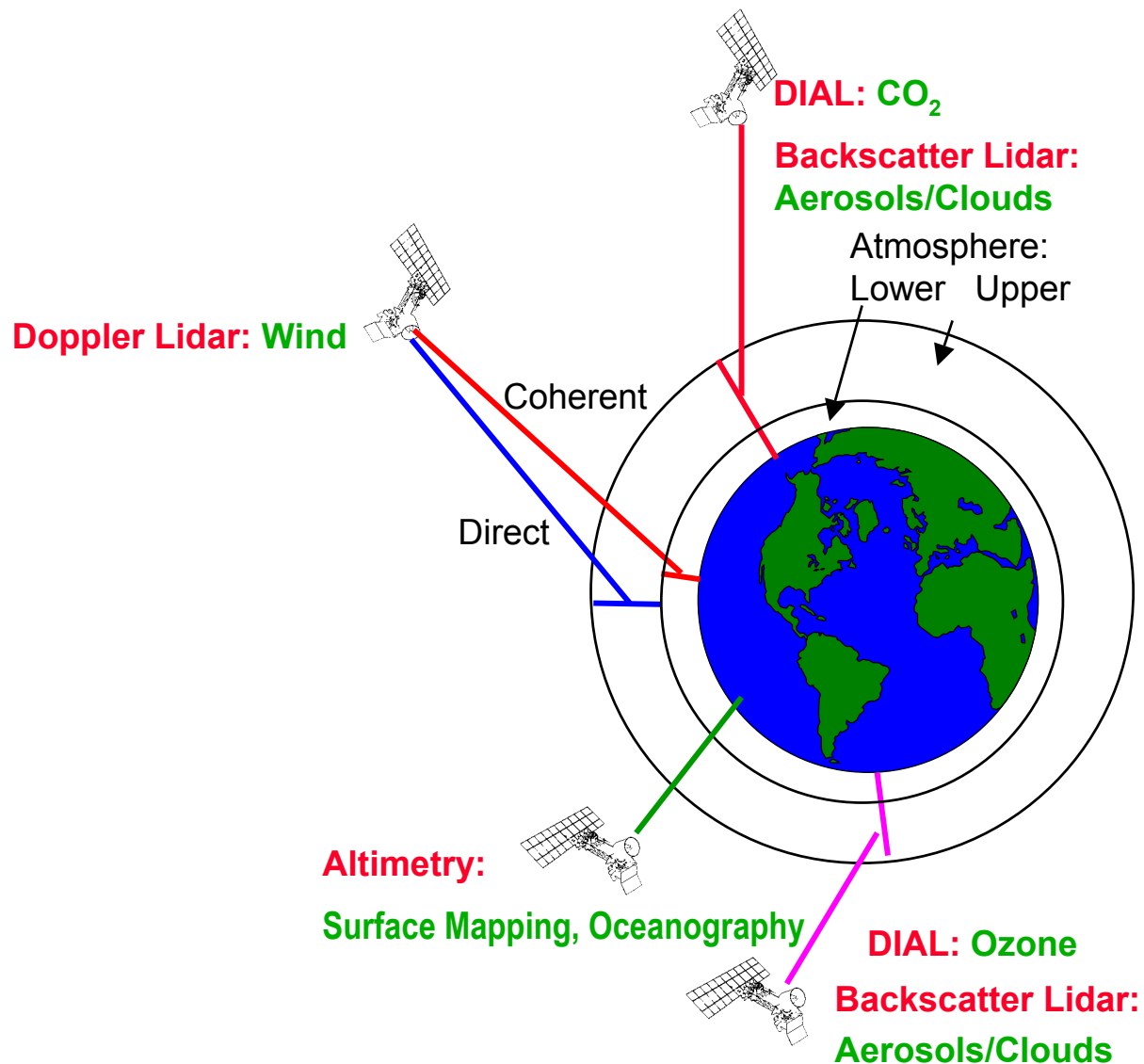
## 6 Priority Measurements

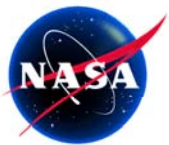




# Earth Sciences Application Focus

**4 Techniques, 6 Priority Measurements**





# Earth Sciences Application Focus

2 Lasers, 4 Techniques, 6 Priority Measurements

Pulsed  
Laser Development

2 MICRON

1 MICRON

Doppler Lidar: Wind

2.05 micron

2.05 micron

DIAL: CO<sub>2</sub>

Backscatter Lidar:  
Aerosols/Clouds

Atmosphere:  
Lower Upper

Coherent

Direct

0.355 micron

X3

1.06 micron

X2

0.532 micron

X2

OPO

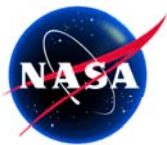
Altimetry:

Surface Mapping, Oceanography

0.30-0.32 micron

DIAL: Ozone

Backscatter Lidar:  
Aerosols/Clouds



# Earth Sciences Application Focus

2 Lasers, 4 Techniques, 6 Priority Measurements

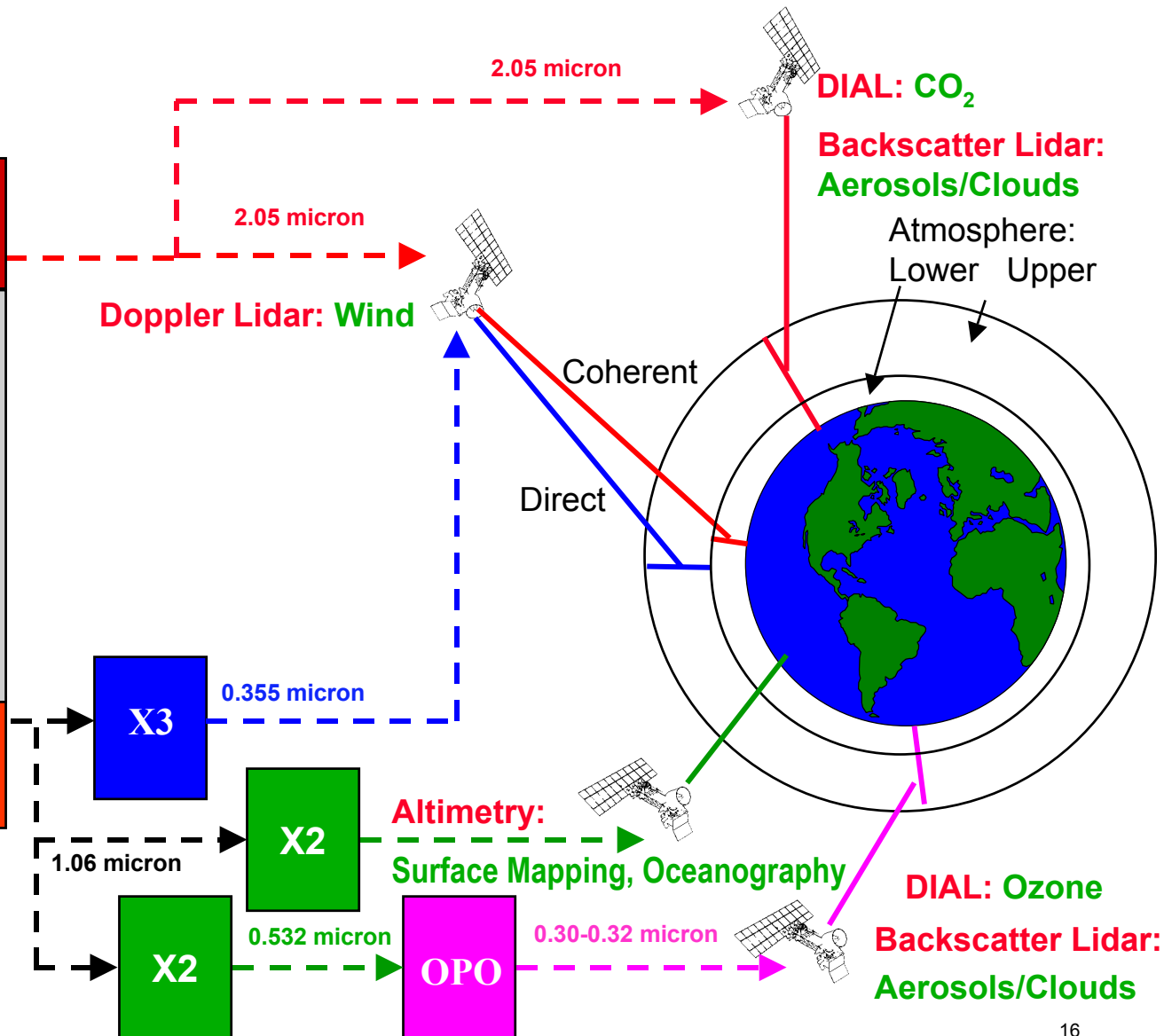
## Pulsed Laser Development

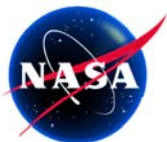
**2 MICRON**

### Key Technologies in Common

- Laser Diodes
- Laser Induced Damage
- Frequency Control
- Electrical Efficiency
- Heat Removal
- Ruggedness
- Lifetime
- Contamination Tolerance

**1 MICRON**





# Laser Transmitter Testbeds

Contamination Tolerance

Now: 50, A/10

Goal: Better Tolerance

Laser Induced Damage

Now: 15 J/cm<sup>2</sup> for 5 nsec

Goal: 60 J/cm<sup>2</sup> for 5 nsec

Ruggedness

Now: 1 min @ 10G

Goal: 1 min @ 15 G

Lifetime

Now: 850? M shots

Goal: 2 G shots

Heat Removal

Now: 110 Watts

Goal: 300 Watts

Frequency Control

Now: < .25 pm

Goal: < .005 pm

2  $\mu$  Test Bed

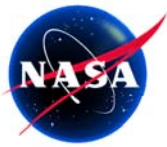
1  $\mu$  Test Bed

Knowledge

Electrical Efficiency

Now: 3-4%

Goal: 6%

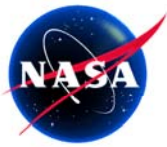


# Laser-Diode-Array Technologies

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## Conductive-Cooled, Long-Life, Efficient, High-Power Laser Diode Arrays for Ground, Air, and Space-based Lidar Missions

- Develop requirements
- Assess laser diode developers and investigate partnering to develop laser diodes to meet NASA's requirements
- Establish multi-year program with select vendors for research, development, testing, and characterization of space-based laser diode arrays
- Establish in-house spectral, lifetime, de-rating testing and characterization capabilities at the Centers, e.g.,
  - Lifetime testing, Environmental testing
  - Spectral Characterization

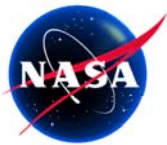


# Related Tunable Technologies

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Additional tunable technologies can extend the capabilities of the basic laser transmitters to fulfill the full range of priority applications. Examples include:

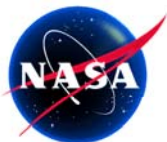
- Wavelength Generation and Tunability
  - Harmonic Generation
    - 2X Cloud and Aerosols
    - 3X Direct Detection Wind
  - Optical Parametric Oscillator and Amplifiers
    - Chemical Species Detection
      - » (e.g., Ozone, CO<sub>2</sub>, Chemical and Biological agents)



# Recommendations

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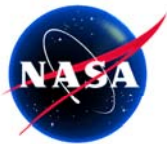
- **Establishing Space-hardened Laser Transmitter Test Beds** ( $1\mu\text{m}$  laser at GSFC &  $2\mu\text{m}$  at LaRC)
- **Development and Qualifications of Space-based Laser Diode Arrays**
- **Advancing Wavelength Conversion Technology for Space-based Lidars**



# Resource Requirements

TASK	FY 03	FY 04	FY 05	FY 06	FY 07
	\$M	\$M	\$M	\$M	\$M
1 <sub>μ</sub> TEST BED (GSFC)	2.0	2.0	3.0	2.0	2.0
2 <sub>μ</sub> TEST BED (LARC)	3.0	3.0	3.0	2.0	2.0
LASER DIODES	2.0	2.0	2.0	2.0	2.0
WAVELENGTH CONVERSION	2.0	3.0	3.0	2.0	2.0
TOTAL	9.0	10.0	11.0	8.0	8.0

Funding levels targeted at attaining TRL 5 or better for components needed for typical lidar missions

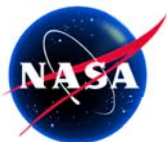


# Advanced Active Instrument Technology

Proposed Augmentation for FY03

Code R

**Draft Copy**



# Advanced Active Instrument Technology

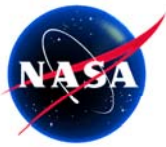
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- **Major Program Elements**

- Space-hardened Advanced Laser Transmitter Technologies Test Beds
- Efficient, High-power, Conductive-cooled Space-hardened Laser Diode Arrays Technologies
- Non-linear Optical Parametric and Harmonic Generation Technologies
- “Intelligent” Receivers, Tunable, Processing at the Focal Plane
- Life Prediction Methods

- **Budgetary Resources (\$M)**

FY 03	FY 04	FY 05	FY 06	FY 07
12.0	16.0	16.0	16.0	10.0



# Advanced Lidar Receiver Technologies

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**Advanced Lidar Receiver Technology with active/intelligent devices is critical to successful development of relatively large aperture space-based Lidars.**

***Advanced Lidar Receiver Technology* can be classified under four major elements:**

- **Automatic Optical Alignment**

**Active pixel array** technologies combined with **intelligent autonomous controller** to maintain instrument optical alignment and correct for distortions

- **Integrated Photoreceiver**

Integrating **detectors**, **processing electronics**, and **Tunable Semiconductor Local Oscillator Laser**, on a single chip for improved lidar sensitivity and robustness.

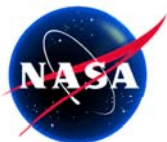
- **Scanner**

**Non-mechanical electro-optical devices** to mitigate many technical issues associated with the scanning lidar instruments.

- **Lightweight Lidar Telescope**

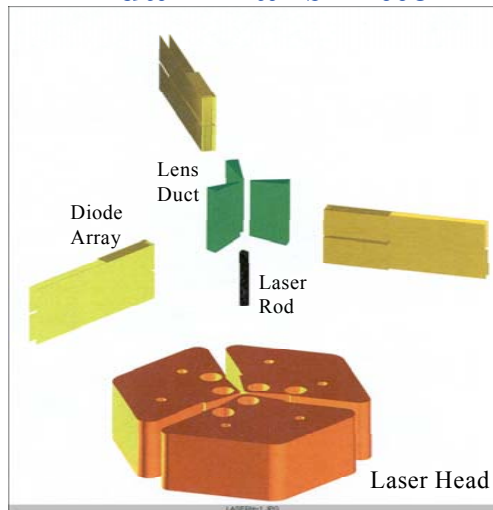
Advanced telescope technologies leading to **Meter-class** lightweight telescope are needed for Coherent Doppler and Backscatter Lidars. **Multi-meter Deployable** Telescopes are critical to DIAL applications.

**Deliverables** - Proof of concept test bed for advanced lidar receivers applicable to direct and coherent lidar systems

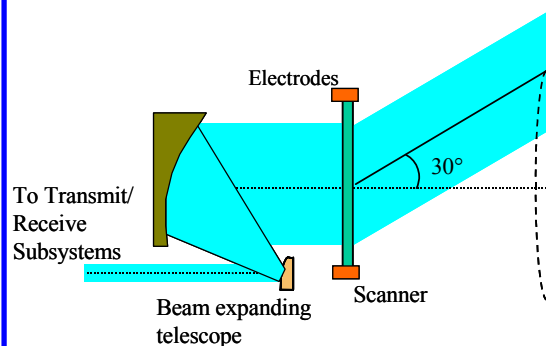


# Major Lidar Technology Elements

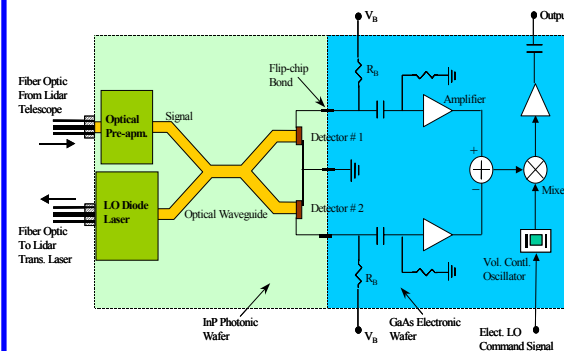
## Lidar Transmitter



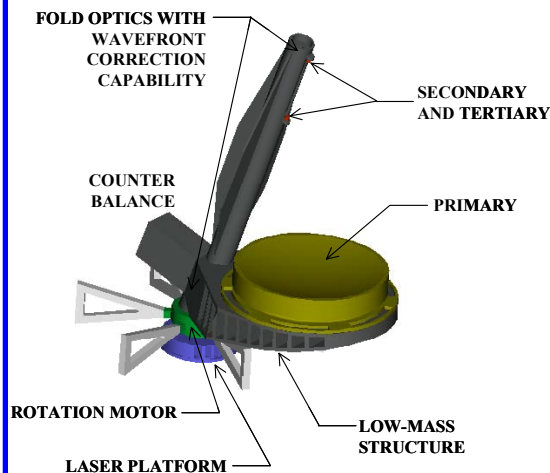
## Electro-Optic Scanner



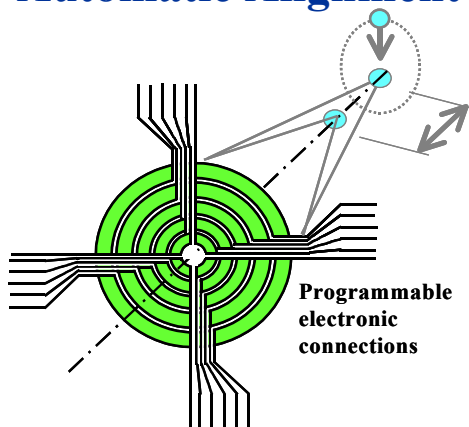
## Integrated Photoreceiver



## Lightweight Telescope

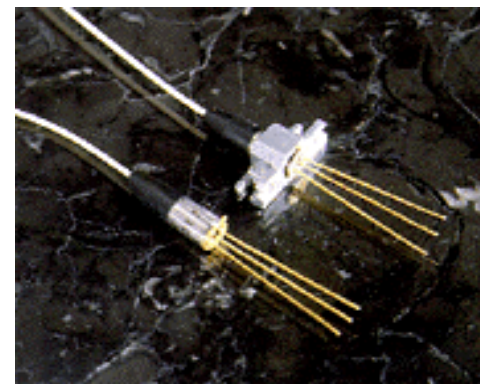


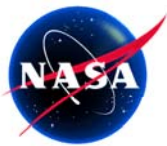
## Automatic Alignment



Schematic of PLZT-based Adjustable Focus and tip/tilt, and Aberration Correction

## Low-Noise Detector





# Advanced Active Instrument Technology Deliverables

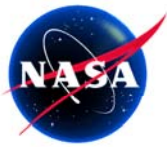
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## Near Term

- 1 and 2-micron Laser Transmitter Test Bed
  - Trade off studies for oscillators and amplifiers designs
  - Trial designs for conductive cooling
  - Prototype laser package designs
- Laser Diode Qualification
  - Identification of potential sources
  - Diode testing protocols and testing facilities
- Related Tunable Technologies - Non-linear optics test facilities
- Advanced Lidar Receiver Technologies -Active pixel array technologies, deployable and lightweight telescope

## Program End

- Space-hardened 1- and 2-micron Laser Transmitters (Efficient, conductively-cooled)
- Space-hardened Conductively Cooled Laser Diode Arrays
- Non-linear Optical Parametric and Harmonic Generation for Ozone, Chemical and Biological Species, and Carbon Dioxide Detection
- Advanced Lidar Receivers for Direct and Coherent lidars
- Life Prediction Methods for Active Instrument Components



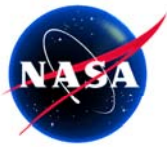
# Advanced Active Instrument Technology

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## Lead and Performing Center Roles

### Overall lead for Code R Advanced Active Instrument Technology Program element - LaRC

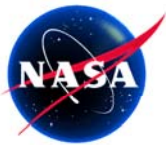
- **Advanced Active Instrument Technology (LaRC)**
  - 2-micron Laser Transmitter Test Bed Implementation – LaRC
  - 1-micron Laser Transmitter Test Bed Implementation– GSFC
  - Non-Linear Optical Parametric Technologies Developments– LaRC
  - Harmonic Generation Technology Development – GSFC
  - Laser Diode Arrays Development – LaRC and GSFC Collaboration
  - Participation in Space Technology Alliance - LaRC and GSFC Collaboration
  - “Intelligent” Receivers, Tunable, Processing at the Focal Plane – LaRC, JPL and ARC
  - Life Prediction Methods - LaRC and ARC



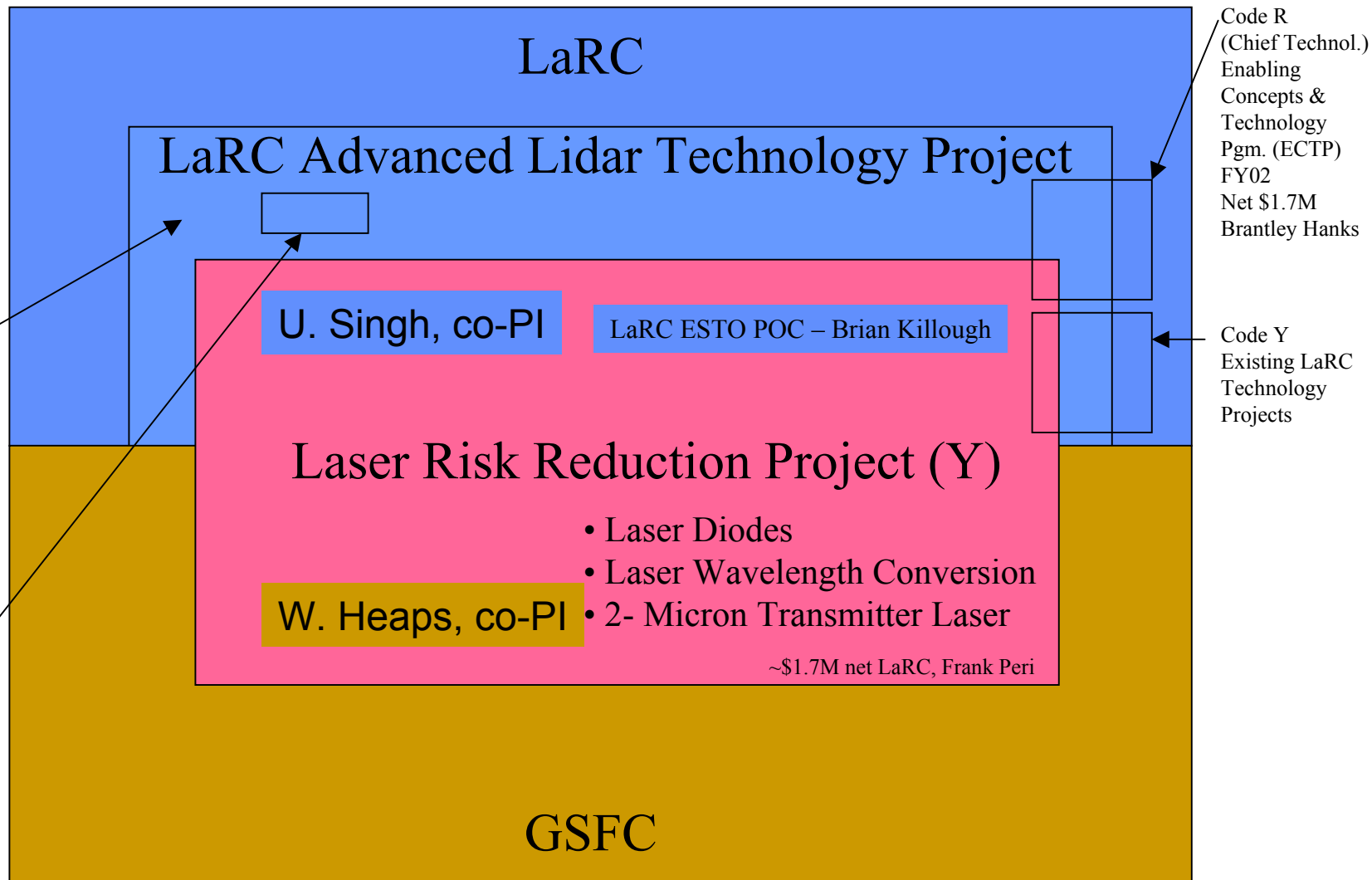
# Status Of Proposal

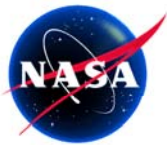
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- FY02 Code Y Start Money Approved (\$4M, ~ \$1.7 M net to LaRC ALTP – LaRC PI- U. Singh, GSFC PI- W. Heaps)
- FY02 Code R Start Money Approved (\$1.7M net to LaRC ALTP)
- Code R FY 03 Augmentation Request was presented to OMB for New Line Approval for FY03 (\$ 70M for FY 03-07, Program Lead: U. Singh, LaRC, Deputy: W. Heaps, GSFC, Deputy: TBD ARC)



# Advanced Lidar Technology Project





# Funded FY02 Activities

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## Code Y/ESTO (New)

- Laser Diode Test Facility & Improvement
- Laser Wavelength Conversion Technology
- 2-Micron Laser Transmitter Technology

## Code R (New)

- 2-Micron Laser Transmitter Technology
- Quantum Mechanical Modeling; New Materials
- Laser Wavelength Conversion Technology
- Detector Technology
- Integrated Lidar Receiver Technology

## Code Y (Existing)

- 2-micron Lidar Transmitter
- Water Vapor Lidar

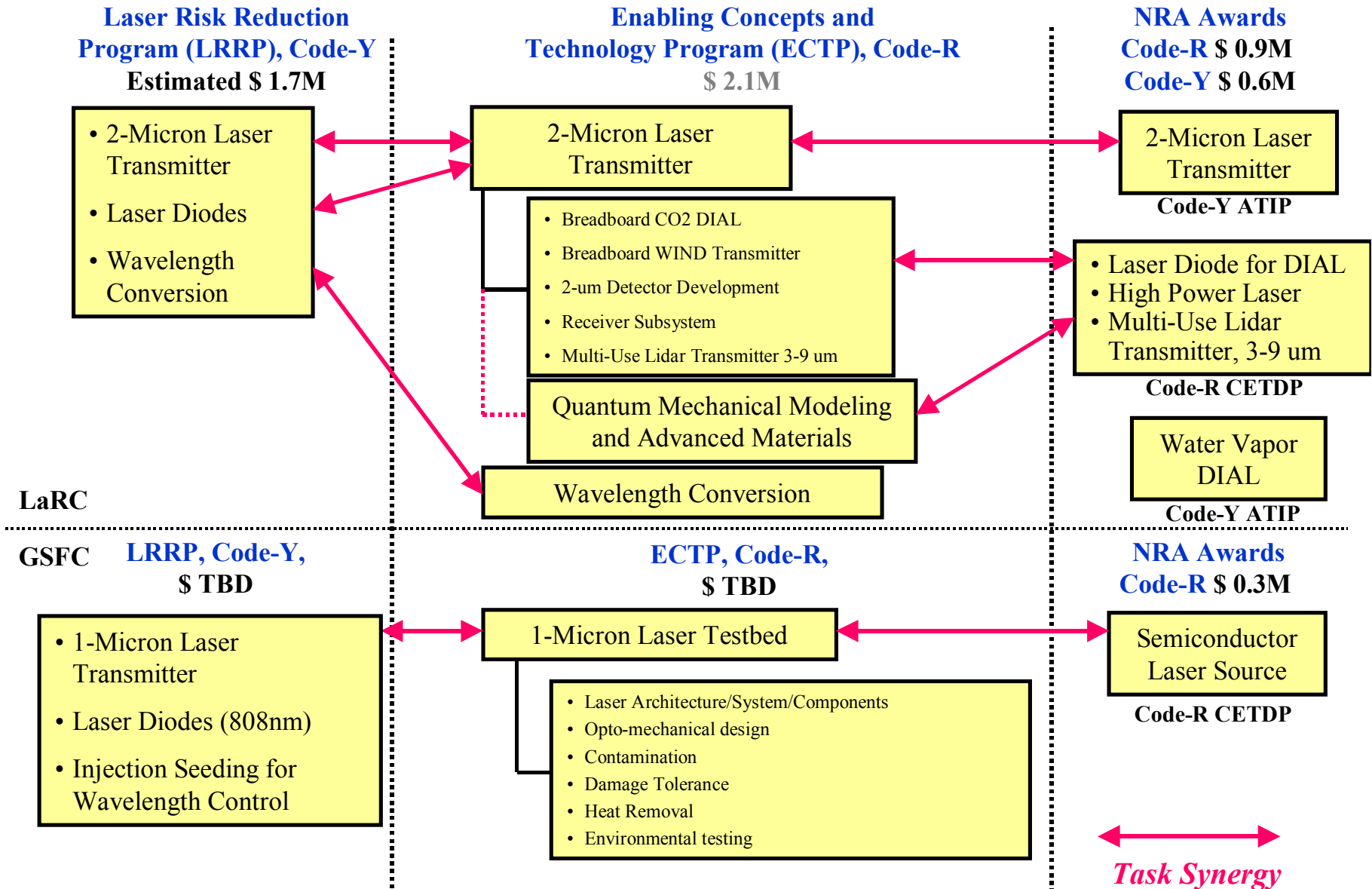
## Code R (Existing)

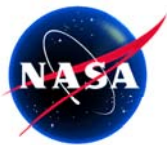
- Multiple Lidar Transmitter

## Code Y and IPO (Existing)

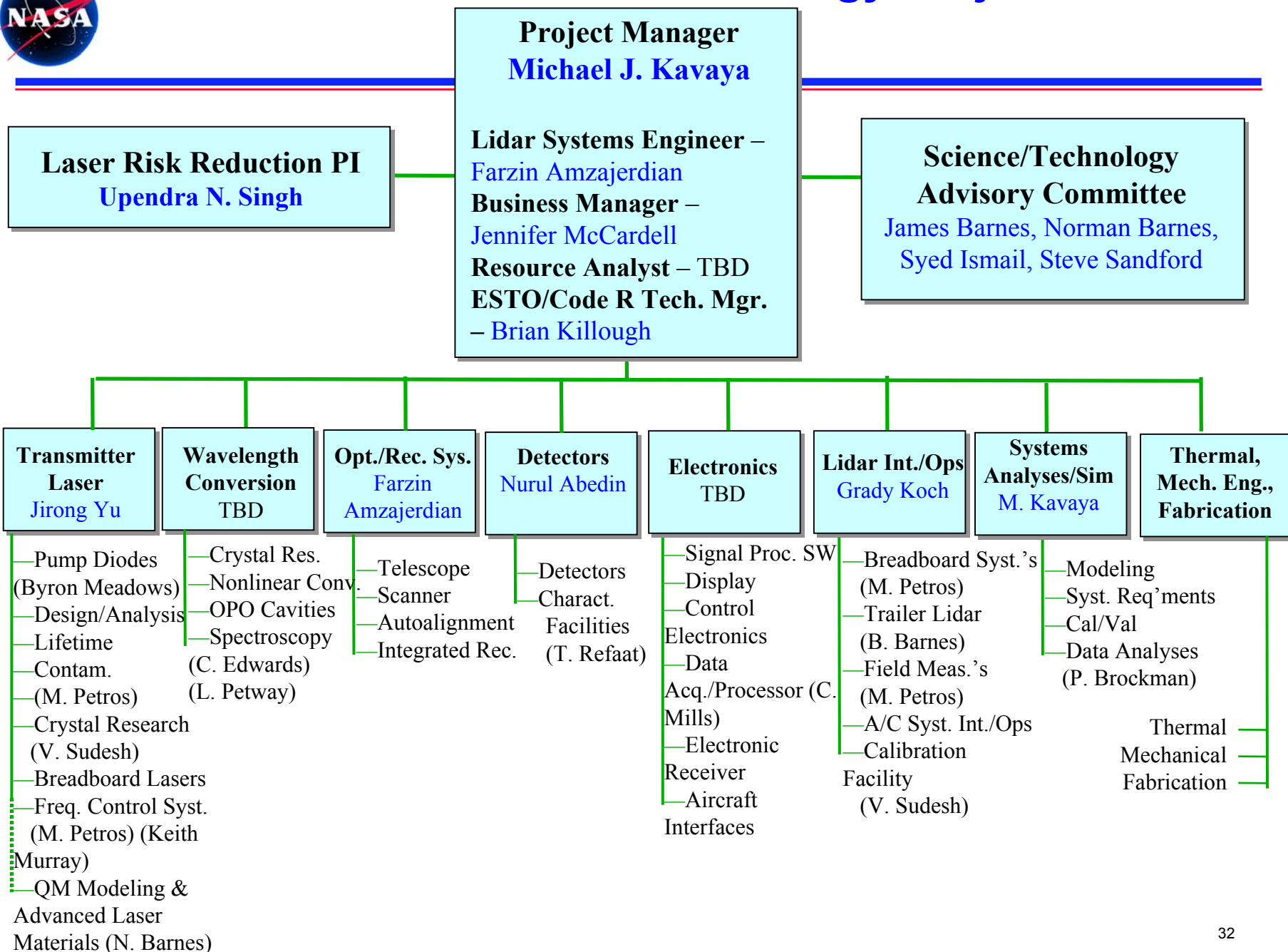
- Lidar Trailer Activities
- Lidar Wind Data Buy Support

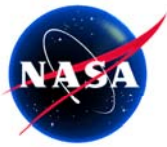
# FY02 Joint Laser Technology Program





# Advanced Lidar Technology Project

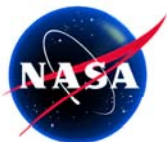




# ALTP Charter

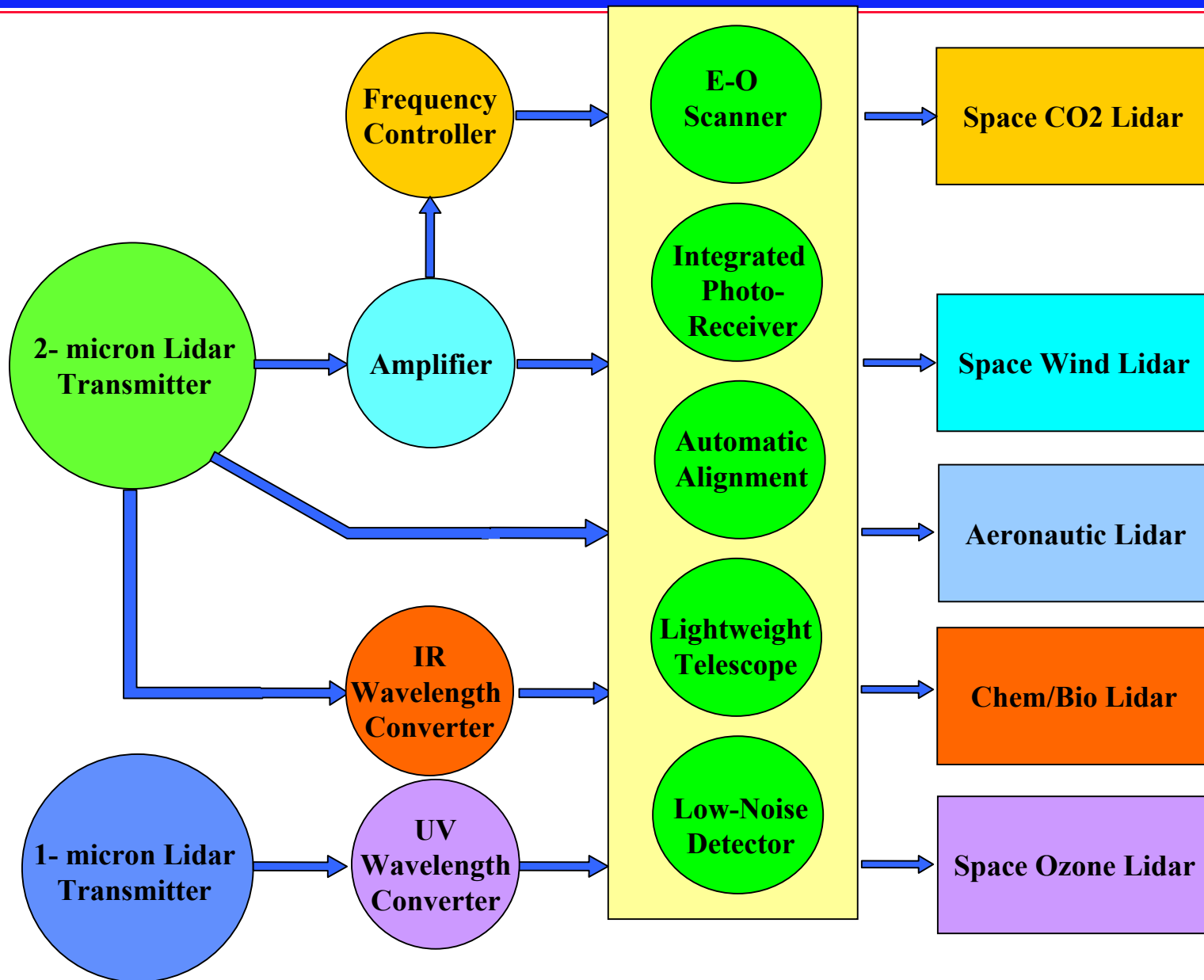
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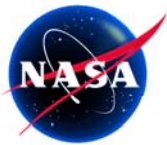
- Develop lidar technology for NASA's future measurements
- Assemble in-house NASA team with end-to-end lidar capability (theory to hardware to validation)
- Collaborate with industry, academia, and government
- Validate technology to reduce risk of space-based lidar missions before the proposal process
- Transfer technology to industry



# End-to-End Lidar Capabilities

## Lidar Technologies

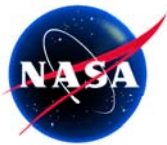




# Conclusions

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- **INLSST formulated a multi-enterprise Integrated NASA lidar system strategy for addressing critical technological deficiencies cited by External Peer Review Committee**
- **INLSST presented the program (technical, schedule, cost) to Center Directors, Associate Administrators and secured their advocacy**
- **INLSST presented the Lidar System Strategy to NASA Administrator and received his approval for funding in FY 02 and go-ahead for an augmentation request in FY 03**
- **Co-Lead from LaRC developed a \$70M Code-R Augmentation Proposal. Capital Investment Council has approved the augmentation request and is awaiting OMB approval**
- **LaRC Team has received \$4M in FY 02 fund from Code Y and R to implement the INLSST strategy**
- **An Advanced Lidar Project Team has been formed at LaRC to carry out the proposed strategy and develop an end-to-end lidar capability**



# Acknowledgements

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## **INLSST Team**

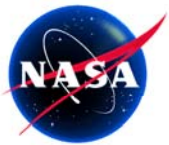
- Robert Afzal
- Norm Barnes
- Bruce Gentry
- Bill Heaps
- Syed Ismail

## **LaRC Support Team**

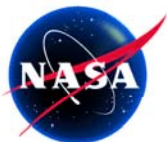
- Jerry Creedon
- Ruth Martin
- Steve Sandford
- Glenn Taylor
- Carl Gray
- Lenny McMaster
- Michael Kavaya
- Farzin Amzajerian
- Edward V. Browell
- James Barnes
- Barry Meredith
- Brian Killough

## **HQ/GSFC Team**

- Sam Venneri
- Ghassem Asrar
- Tom Wagner
- Brantley Hanks
- Al Diaz
- George Komar
- Mary Kicza
- Frank Peri



# Backup Slides



# Advanced Active Instrument Technology

## Backscatter Lidar

### Measurements:

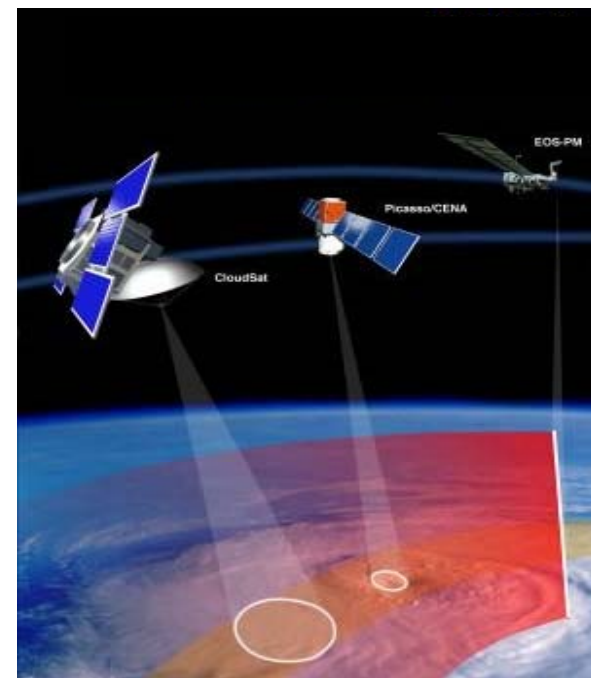
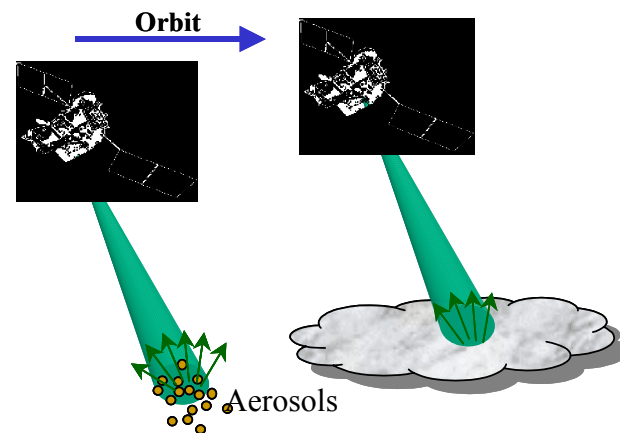
- Cloud Base and Top Heights
- Cloud Density
- Aerosol Concentration
- Provide Transport Data and Seasonal Changes

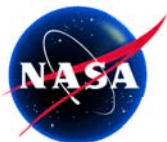
### Instrument Description:

- Transmit short/medium duration laser pulses ( $10 \text{ nsec} < \tau_p < 100 \text{ nsec}$ )
- Reflected photons are collected by a telescope
- Intensity and polarization of reflected light provide Aerosol and Cloud density and effective particle size
- Pulses round-trip time provide accurate Aerosol and Cloud vertical distributions

### Instrument Attributes:

- Non-scanning
- Meter class Telescope
- 20 W class Laser
- Level of Complexity: Moderate-to-High





# Advanced Active Instrument Technology

## Altimeter Lidar

### Measurements:

- Vegetation and Land Topography
- Ice Sheet Mass Balance
- Ocean Surface and Current Flow
- Provide Associated Temporal Changes

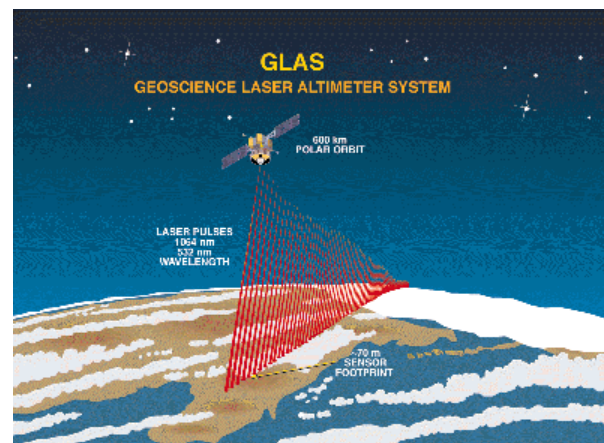
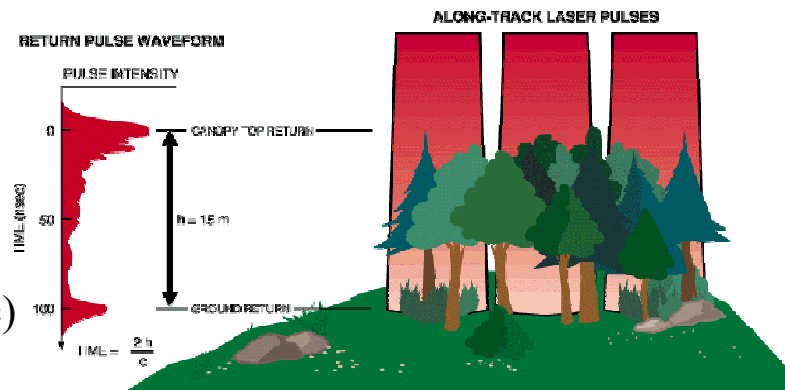
### Instrument Description:

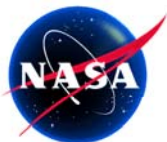
- Transmit short duration laser pulses ( $\tau_p < 5$  nsec)
- Reflected photons are collected by a telescope
- Pulses round-trip time provide accurate distances to targets of interest
- More sophisticated signal processing allows for measurements of extended targets such as vegetation height

### Instrument Attributes:

- Non-scanning
- Sub-meter class Telescope
- Sub 10 W class Laser
- Level of Complexity: Moderate

### LASER ALTIMETER PULSE SPREADING FOR MEASUREMENT OF VEGETATION HEIGHT AND SUB-CANOPY TOPOGRAPHY





# Advanced Active Instrument Technology

## Coherent Doppler Lidar

### Measurements:

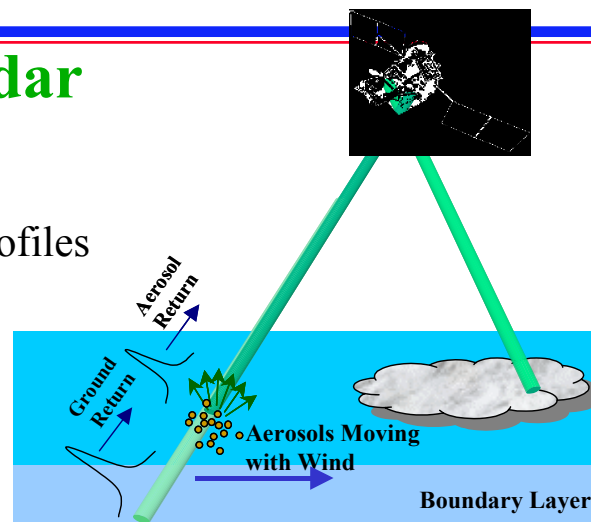
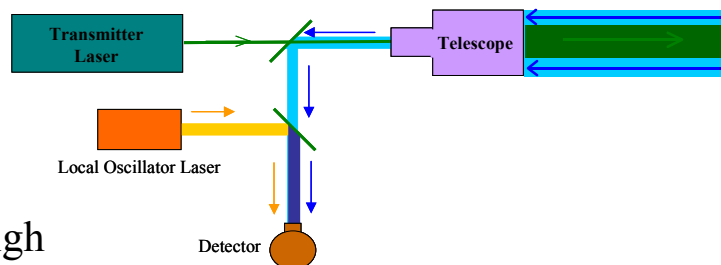
- Boundary Layer and Lower Troposphere Wind Velocity Profiles
- Cloud Height and Velocity
- Aerosol Concentration
- River Flow

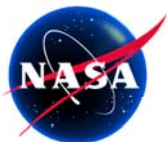
### Instrument Description:

- Transmit medium duration laser pulses ( $\tau_p > 200$  nsec)
- Reflected photons from atmospheric aerosols are collected by a telescope
- Wavelength of the backscattered light is Doppler shifted by aerosols moving with wind
- Doppler shift is measured using heterodyne detection similar to FM radio

### Instrument Attributes:

- Scanning
- Meter class Telescope
- 10 W class Laser
- Level of Complexity: High





# Advanced Active Instrument Technology

## Direct Detection Doppler Lidar

### Measurements:

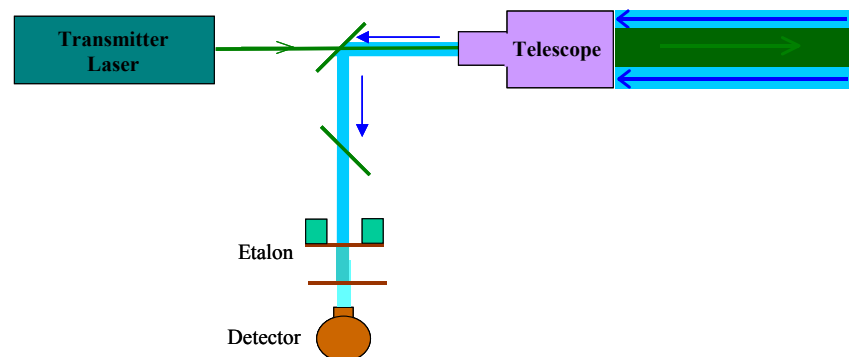
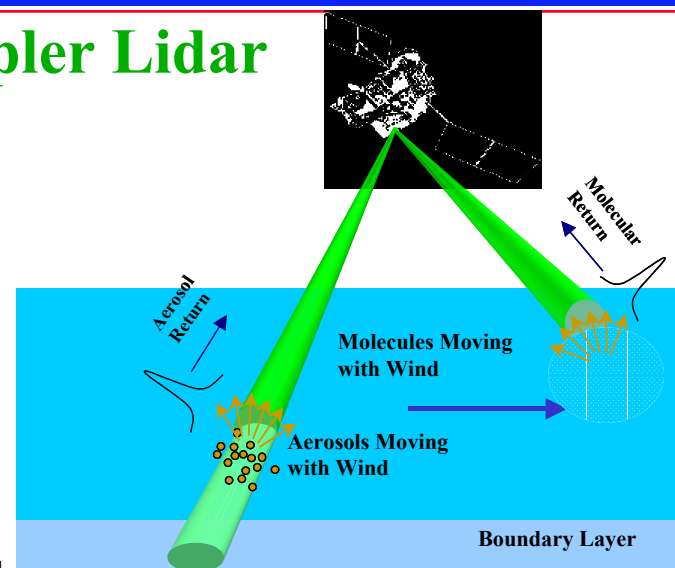
- Troposphere Wind Velocity Profiles
- Cloud Height

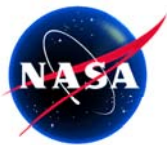
### Instrument Description:

- Transmit short duration laser pulses ( $\tau_p < 20$  nsec)
- Reflected photons from atmospheric molecules and aerosols are collected by a telescope
- Wavelength of the backscattered light is Doppler shifted by molecules and aerosols moving with wind
- Doppler shift is measured using Fabry Perot Etalons

### Instrument Attributes:

- Scanning
- 2-Meter class Telescope
- 30 W class Laser
- Level of Complexity: High





# Advanced Active Instrument Technology

## Differential Absorption Lidar (DIAL)

### Measurements:

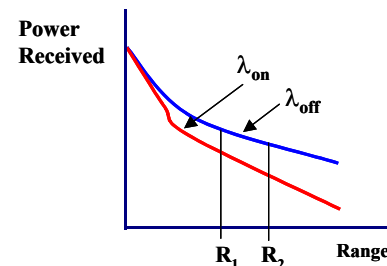
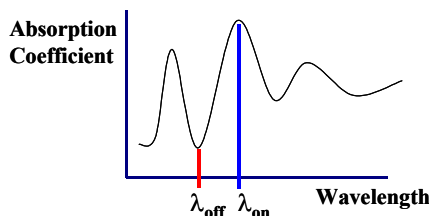
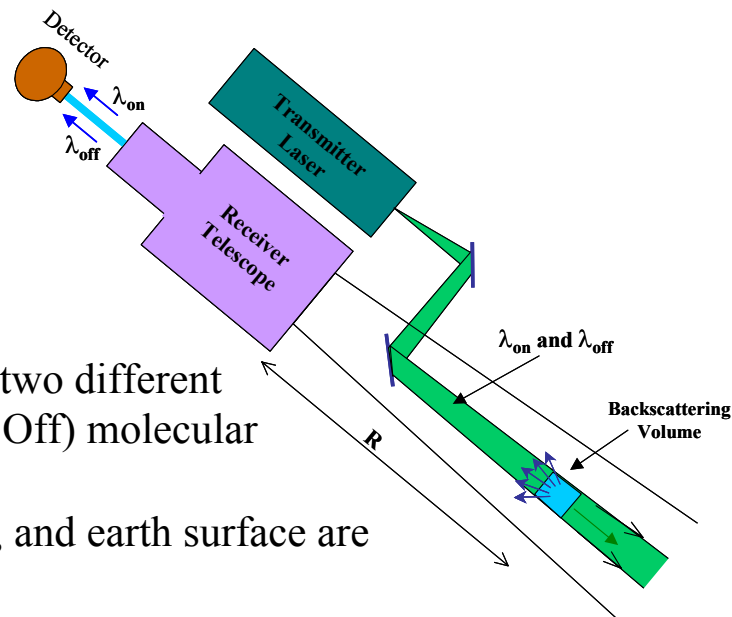
- Carbon Dioxide (CO<sub>2</sub>) Concentration Profiles
- Ozone (O<sub>3</sub>) Concentration Profiles
- Cloud Base and Top Heights, and Density
- Aerosol Concentration

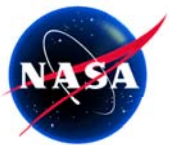
### Instrument Description:

- Transmit short duration laser pulses ( $\tau_p < 20$  nsec) at two different wavelengths, corresponding to high and low (On and Off) molecular absorption lines
- Reflected photons from atmospheric aerosols, clouds, and earth surface are collected by a telescope
- Ratio of the backscattered light at On and Off wavelengths provides molecular concentration
- CO<sub>2</sub> is measured by a 2-micron lidar and O<sub>3</sub> by a 0.3-micron lidar

### Instrument Attributes:

- Non-scanning
- 2-Meter class Telescope
- 10 W class Laser
- Level of Complexity: High





# Advanced Active Instrument Technology

## SPACE SCIENCE MISSIONS

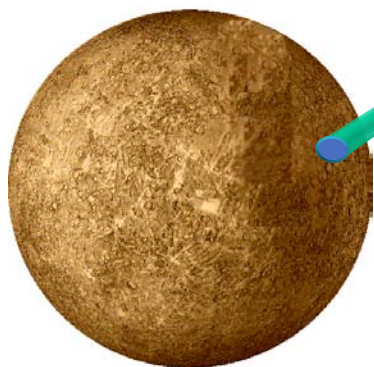


### Planetary Orbiting Lidars

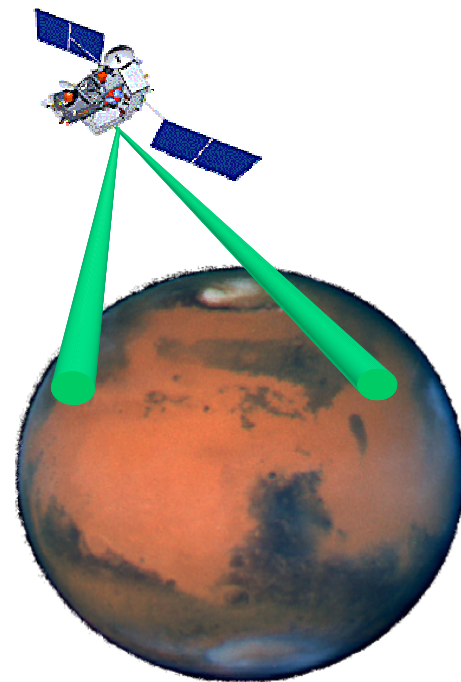
- Concentration, distributions, and variations of  $\text{CO}_2$ ,  $\text{O}_3$ ,  $\text{H}_2\text{O}$
- Wind fields and seasonal variability
- Altimetry and Surface Topography

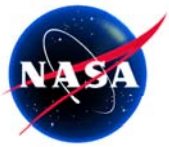
### Planetary Lower Atmosphere Sensing

- $\text{CO}_2$ ,  $\text{O}_3$ ,  $\text{H}_2\text{O}$
- Wind Velocity
- Dust Opacity



MESSENGER MLA  
Mercury Laser Altimeter

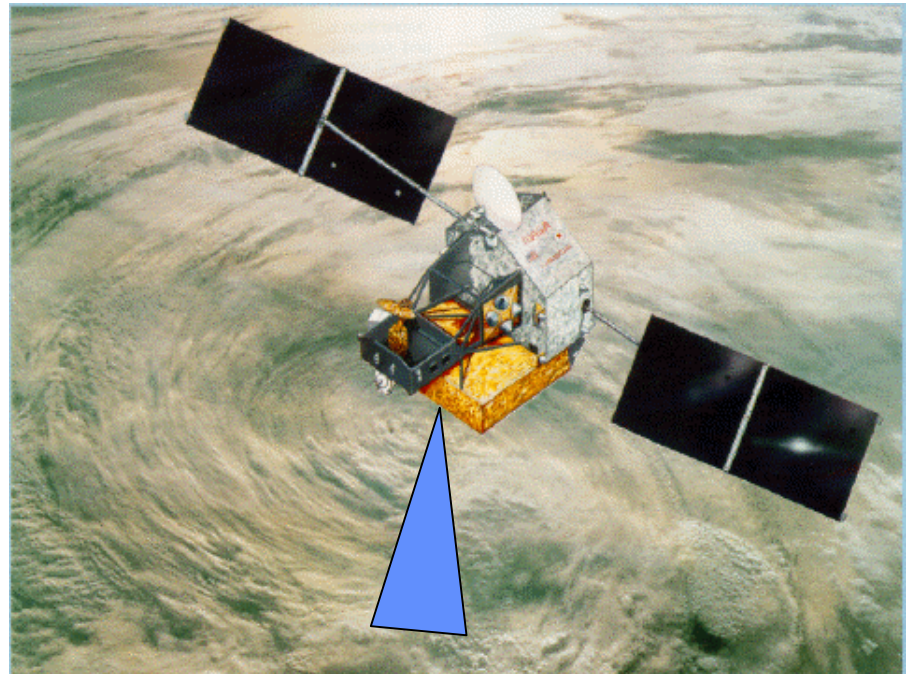




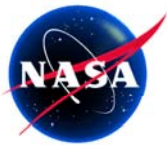
# Lidar for Earth Sciences Enterprise

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**Lidar Instruments are capable of providing high vertical resolution global measurements of Ozone, Carbon dioxide (CO<sub>2</sub>), water vapor, and aerosol concentration from space. Laser altimeters can provide surface mapping, ice topography, and ocean stream/current measurements from space**

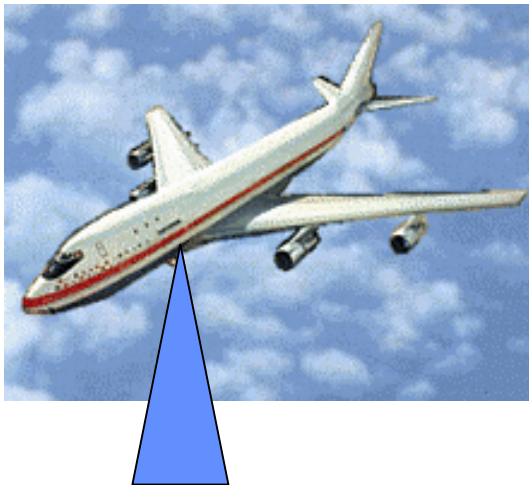


**ESE recognizes the merits of Lidar technology for achieving these measurements.**



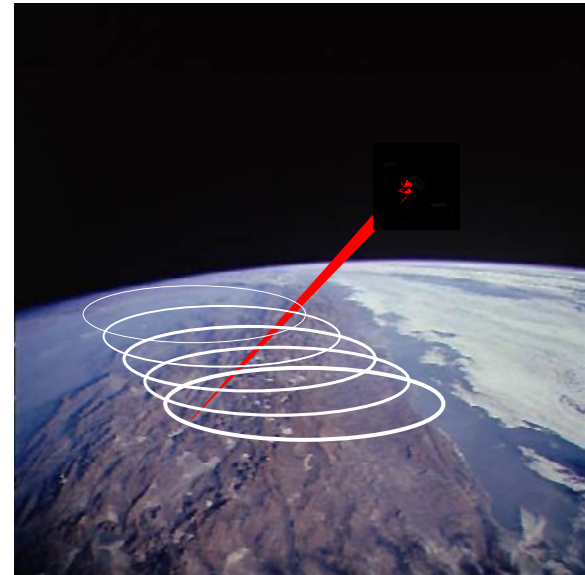
# Lidar for Earth Sciences Enterprise

*Lack of accurate global wind data has been cited by the ESE as a major missing component in the presently planned set of measurements*



Lidar wind measurements from an aircraft provide valuable data for:

- Scientific investigation of sub-grid processes and features in climate and global change models
- Assessment of the performance of proposed space-based Doppler lidars
- Provide calibration and validation data for space-based Doppler lidars



*“Direct tropospheric wind measurements would provide a greater impact on numerical weather prediction models than any other new space-based observation.” - NPOESS IPO, 1996.*